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Mid-term Progress Report
CRP F11016

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1) Scientific scope of your project under the CRP (please provide a short paragraph on your role in the CRP)

SNL is tasked with performing electrical characterization, irradiation, and IBIC, DLTS, C-V measurements on devices used in the CRP, calculating damage and ionization profiles for modeling.

2) Research Objectives (please refer to your tasks in the CRP workplan)

- Electrical characterization of Helsinki diodes pre and post irradiation
- Irradiation of Helsinki diodes with different energy He beams
- IBIC characterization of irradiated Helsinki diodes
- Assessment of full area irradiation and performing it if it is feasible
- DLTS and C-V measurements on full area irradiated diodes
- Ion transport calculations to determine ionization and damage profile for the irradiations performed.
- Modeling IBIC using TCAD if feasible

3) Work has been done and results achieved since the beginning of the CRP (please refer to the workplan/CRP outputs and outcomes)

- Helsinki diodes were electrically characterized (doping, depletion depth vs. bias, etc.) and the data was provided for the CRP participants.
- Damage and ionization profiles were determined for several He energies used in the CRP and the data made available to the CRP participants
- Helsinki diodes were characterized using 2 MeV He IBIC then they were irradiated with various energy He beams. The damage was measured by IBIC in-situ and after completing the irradiation. The CCE degradation as the function of the irradiation fluence was determined and provided to University of Torino for modeling.
- Full area irradiations were performed using the SNL pulsed irradiation system with He and H beams. The devices were characterized by IBIC, C-V, and I-V measurements. These irradiations resulted in large increase in the leakage current, which made IBIC measurements difficult.
- Electron irradiated (JAEA) Helsinki diodes were electrically characterized and IBIC measurements were performed on them.
- New method was developed to use Marlowe to determine absolute number of Frenkel-pairs more precisely.
- DLTS and C-V measurements were performed on a Helsinki diode and two PIN diodes that were irradiated at ANSTO.

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- Various Hamamatsu PIN diodes were tested that might be used in CRP.
- Helsinki diodes and various Hamamatsu PINs were irradiated in the SNL Annual Core Research Reactor with neutrons. The damage was measured by IBIC and the diodes were electrically characterized.
- A preliminary TCAD model of the Helsinki diodes was constructed and charge induction due to 2 MeV He ions was modeled.

4) Work has been done and results achieved since the 2nd RCM (13-17 May 2013), please refer to the workplan/CRP outputs and outcomes (this will be part of the previous point but please make it clear what has been done since the 2nd RCM)

- New method was developed to use Marlowe to provide better absolute values of Frenkel-pairs
    - It was discovered that Marlowe was incorrectly used in the past. Marlowe does not use the concept of displacement energy, only binding energy. This way even if we use the Marlowe pairing scheme and keep only the distant pairs it will overestimate the number of Frenkel-pairs created.
    - In collaboration with Stephen Foiles of SNL a recombination radius for Si was determined by comparing Marlowe's results to Molecular Dynamics calculation. This radius is in the order of 7 Å and eliminates a large fraction of pairs classified as distant pairs.
- DLTS and C-V measurements were performed on diodes irradiated at ANSTO using a scanned ion beam. The full area of the diodes was irradiated in order to perform C-V measurements and DLTS. The result were communicated to ANSO and RBI, and a short discussion took place with Ivana Capan of RBI about the DLTS results last December during the mini CRP meeting.
- Since the Helsinki diodes might not be the best devices for this study several Hamatsu PIN and regular diodes were tested. With some of the diodes (S2386 and S5973) we found that after the CEE saturated at some bias value, increasing the bias further started an increase in the CEE. This increase in the induced charge might indicate avalanche formation that might be worth investigating.
- Helsinki and Hamatsu diodes were irradiated in the SNL ACRR by neutrons and were characterized electrically and by IBIC. We found the damage levels we used in our previous studies with the microbeam, in this case increase the leakage current so much that it is practically impossible to perform IBIC at any bias but 0 V (or very low). This suggests that we might have to use the full area irradiation only for C-V and DLTS measurements and continue to use small area irradiation for IBIC.
- A 2D TCAD model of the Helsinki diode was constructed using Silvaco's ATLAS to compare its calculation of charge induction to the Vittone model. At this point only undamaged calculations were done modeling the ion beam track as constant charge column. These calculations showed an interesting effect that the 1D Vittone model cannot account for. We found that due to the very low doping of these diodes, even this relatively low density plasma pushes the electric field out of the trajectory volume and it takes a long time for the electric field to relax back to its original state. This can have an important effect on the charge collection efficiency in damaged diodes and might explain the problems with the current model.

5) Work to be done before the 3rd RCM (please refer to the workplan)

- If required and samples (either Si or SiC diodes) are provided further irradiations will be performed by ions and neutrons. The devices will be characterized electrically and by IBIC as usual.
- Further ATLAS calculations will be done by refining the trajectory definition and adding damage to the model. We will attempt to determine how large the effects due to the field modification by the e-h plasma.

6) Impact of your participation in the CRP (e.g. creating new collaborations, opening new training opportunities new topics for MSc, PhD, improving the international recognition of your work/laboratory, improving your competitiveness in getting grants etc.)

No new collaboration was established apart from working with the CRP participants.

7) Publications/talks etc.

None yet.

8) Diploma/PhD thesis/CRP relevance to education etc.

None.